

## REMARKS

Claims 15-28 are pending in this application. By this Preliminary Amendment, Applicant AMENDS the specification and the Abstract of the Disclosure, CANCEL claims 1-14 and ADD new claims 15-28.

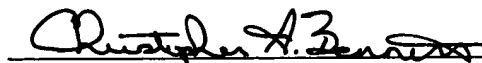
Applicant has attached hereto a Substitute Specification in order to make corrections of minor informalities contained in the originally filed specification. Applicant's undersigned representative hereby declares and states that the Substitute Specification filed concurrently herewith does not add any new matter whatsoever to the above-identified patent application. Accordingly, entry and consideration of the Substitute Specification are respectfully requested.

The changes to the specification have been made to correct minor informalities to facilitate examination of the present application.

Applicant respectfully submits that this application is in condition for allowance. Favorable consideration and prompt allowance are respectfully solicited.

Respectfully submitted,

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- 1 -

## DESCRIPTION

Attorney Docket No. 36856.1313

## 5 BRANCHING FILTER AND COMMUNICATION DEVICE

TECHNICAL BACKGROUND OF THE INVENTION1. Field of the Invention

The present invention relates to a branching filter  
10 including filters having piezoelectric thin film resonators,  
and the branching filter ~~being used~~ is preferably for use in  
a communication device ~~etc,~~ for example.

~~Background~~ 2. Description of the Related Art

15 In recent years, piezoelectric thin film filters using  
elastic bulk waves have been developed.

~~The above~~ Such piezoelectric thin film filters are  
compact in size, ~~have~~ are light weight, and ~~are~~ have  
excellent ~~in~~ vibration resistance and impact resistance. In  
20 addition, the piezoelectric thin film filters have small  
variation in products and high reliability, and can provide  
non-adjusting circuits. Therefore, the mounting process can  
be automated and simplified. Furthermore, even when the  
frequency is increased, the piezoelectric thin film filters

can be easily produced. Thus, the piezoelectric thin film filters have superior characteristics.

A branching filter (duplexer) including such piezoelectric thin film filters ~~is~~has been proposed.

5 For example, Japanese Unexamined Patent Application Publication No. 2001-24476 discloses a branching filter including piezoelectric thin film filters in which the piezoelectric thin film resonators are arranged in a ladder ~~type~~configuration.

10 The piezoelectric thin film resonators used in the branching filter disclosed in Japanese Unexamined Patent Application Publication No. 2001-24476 ~~form~~define a transmitting filter and a receiving filter. In both filters, the electrodes are composed of Mo and piezoelectric thin  
15 films are composed of AlN.

However, the required characteristics are different between the transmitting filter and the receiving filter in the branching filter.

In other words, piezoelectric thin film resonators  
20 having the same structure are optimized only in either the transmitting filter or the receiving filter.

According to the ~~above~~ Japanese Unexamined Patent Application Publication No. 2001-24476, ~~both of the~~ transmitting filter and the receiving filter have the same  
25 structure. Therefore, a branching filter having optimum

- 3 -

characteristics in both ~~of the~~ transmitting and ~~the~~ receiving cannot be achieved.

### Summary of the Invention

In view of the ~~above problems, it is an object~~  
described above, preferred embodiments of the present  
invention ~~to~~ provide a branching filter having excellent  
5 characteristics in which the configuration of the  
transmitting filter and the receiving filter is optimized.

### ~~Disclosure of Invention~~

In order to solve the above problems, a branching  
10 filter of the present invention includes a transmitting  
filter and a receiving filter wherein piezoelectric thin  
film resonators including at least one piezoelectric thin  
film sandwiched between at least one pair of ~~facing~~opposed  
electrodes are ~~disposed~~arranged in a ladder  
15 ~~type~~configuration on an opening or a recess of a substrate,  
the transmitting filter and the receiving filter being  
connected to an antenna terminal in parallel. In the  
branching filter, the piezoelectric thin film resonators  
~~forming~~defining the transmitting filter and the  
20 piezoelectric thin film resonators ~~forming~~defining the  
receiving filter have a different structure.

In the branching filter of preferred embodiments of the  
present invention, the piezoelectric thin film resonators  
~~forming~~defining the transmitting filter and the  
25 piezoelectric thin film resonators ~~forming~~defining the

receiving filter preferably include a different piezoelectric film.

In the branching filter of preferred embodiments of the present invention, the piezoelectric film of the  
5 piezoelectric thin film resonators ~~forming~~defining the transmitting filter is preferably composed of AlN and the piezoelectric film of the piezoelectric thin film resonators ~~forming~~defining the receiving filter is preferably composed of ZnO.

10 In the branching filter of preferred embodiments of the present invention, the material of the electrodes is preferably different between the piezoelectric thin film resonators ~~forming~~defining the transmitting filter and the piezoelectric thin film resonators ~~forming~~defining the  
15 receiving filter.

In the branching filter of preferred embodiments of the present invention, the acoustic impedance of the material of the electrodes is preferably different between the piezoelectric thin film resonators ~~forming~~defining the  
20 transmitting filter and the piezoelectric thin film resonators ~~forming~~defining the receiving filter.

In the branching filter of preferred embodiments of the present invention, the frequency of the pass band of the receiving filter is preferably higher than the frequency of  
25 the pass band of the transmitting filter, and the acoustic

impedance of the material of the electrodes ~~forming~~defining the receiving filter is preferably higher than the acoustic impedance of the material of the electrodes ~~forming~~defining the transmitting filter.

5        In the branching ~~filter~~filter of preferred embodiments of the present invention, the piezoelectric thin film resonators ~~forming~~defining the transmitting filter preferably use second harmonic waves and the piezoelectric thin film resonators ~~forming~~defining the receiving filter  
10        preferably use fundamental waves.

         In the branching filter of preferred embodiments of the present invention, in addition to the above-described configuration, the piezoelectric thin film resonators ~~forming~~defining the transmitting filter and the  
15        piezoelectric thin film resonators ~~forming~~defining the receiving filter preferably include a different insulating film on the opening or the recess of the substrate.

         In the branching filter of preferred embodiments of the present invention, the insulating film of the piezoelectric  
20        thin film resonators ~~forming~~defining the receiving filter is preferably composed of  $\text{SiO}_2$ .

         In the branching ~~filter~~filter of preferred embodiments of the present invention, the insulating film of the piezoelectric thin film resonators ~~forming~~defining the  
25        receiving filter is preferably composed of two layers

including an  $\text{SiO}_2$  layer adjacent to the piezoelectric thin film and an  $\text{Al}_2\text{O}_3$  layer adjacent to the  $\text{SiO}_2$  layer.

In the branching filter of preferred embodiments of the present invention, the insulating film of the piezoelectric thin film resonators ~~forming~~defining the receiving filter is preferably composed of two layers including an  $\text{SiO}_2$  layer adjacent to the piezoelectric thin film and an AlN layer adjacent to the  $\text{SiO}_2$  layer.

In the branching filter of preferred embodiments of the present invention, the insulating film of the piezoelectric thin film resonators ~~forming~~defining the transmitting filter is preferably composed of two layers including an AlN layer adjacent to the piezoelectric thin film and an  $\text{SiO}_2$  layer adjacent to the AlN layer.

In the branching filter of preferred embodiments of the present invention, the insulating film of the piezoelectric thin film resonators ~~forming~~defining the transmitting filter is preferably composed of two layers including an  $\text{Al}_2\text{O}_3$  layer adjacent to the piezoelectric thin film and an  $\text{SiO}_2$  layer adjacent to the  $\text{Al}_2\text{O}_3$  layer.

A communication device of another preferred embodiment of the present invention includes the ~~above~~-branching filter according to one of the preferred embodiments described above.

The branching filter of various preferred embodiments

of the present invention preferably includes a transmitting filter and a receiving filter wherein piezoelectric thin film resonators including at least one piezoelectric thin film sandwiched between at least one pair of ~~facings~~opposed electrodes are ~~disposed~~arranged in a ladder ~~type~~configuration on an opening or a recess of a substrate, the transmitting filter and the receiving filter being connected to an antenna terminal in parallel. In the branching filter, the piezoelectric thin film resonators ~~forming~~defining the transmitting filter and the piezoelectric thin film resonators ~~forming~~defining the receiving filter have a different structure.

According to the above-described unique configuration, the transmitting filter and the receiving filter include piezoelectric thin film resonators having different structures from each other. As a result, a branching filter having optimum characteristics in both of the transmitting filter and the receiving filter can be advantageously provided.

20

— Other features, elements, characteristics and advantages of the present invention will become more apparent from the following detailed description of preferred embodiments with reference to the attached drawings.

25

### Brief Description of the Drawings

Fig. 1 is a circuit diagram of a duplexer according to ~~ana~~ a preferred embodiment of the present invention.

5        Fig. 2 is a schematic cross-sectional view showing the structure of a resonator of a transmitting filter in the duplexer.

      Fig. 3 is a schematic cross-sectional view showing the structure of a resonator of a receiving filter in the  
10        duplexer.

      Fig. 4 is a schematic cross-sectional view showing the structure of a resonator of a receiving filter according to ~~ana~~ a preferred embodiment of the present invention.

      Fig. 5 is a graph showing the displacement of vibration  
15        of each layer in an example of the resonator in Fig. 4.

      Fig. 6 is a graph showing the relationship between the electromechanical coupling coefficient  $k_{eff}^2$  and the film thickness ratio in the resonator in Fig. 4.

      Fig. 7 is a graph showing the relationship between Q  
20        factor and the film thickness ratio in the resonator in Fig. 4.

      Fig. 8 is a graph showing the relationship between the temperature coefficient of frequency (TCF) and the film thickness ratio in the resonator in Fig. 4.

25        Fig. 9 is a schematic cross-sectional view showing the

structure of the resonator in a transmitting filter according to ana preferred embodiment of the present invention.

Fig. 10 is a graph showing the displacement of  
5 vibration of each layer in an example of the resonator in Fig. 9.

Fig. 11 is a graph showing the relationship between  $k_{eff}^2$  and the film thickness ratio in the resonator in Fig. 9.

Fig. 12 is a graph showing the relationship between Q  
10 factor and the film thickness ratio in the resonator in Fig. 9.

Fig. 13 is a graph showing the relationship between TCF and the film thickness ratio in the resonator in Fig. 9.

Fig. 14 is a circuit diagram showing a modification of  
15 the duplexer.

Fig. 15 is a circuit diagram showing a modification of the duplexer.

Fig. 16 is a circuit diagram showing a modification of the duplexer.

20 Fig. 17 is a schematic cross-sectional view showing a modification of the resonator in the transmitting filter and the receiving filter.

Fig. 18 is a graph showing the frequency characteristics of insertion loss in a transmitting filter  
25 and a receiving filter according to ana preferred embodiment

of the present invention.

Fig. 19 is a graph showing the frequency characteristics of insertion loss in a transmitting filter and a receiving filter according to ana preferred embodiment  
5 of the present invention.

Fig. 20 is a graph showing the frequency characteristics of insertion loss in a transmitting filter and a receiving filter in a comparative example.

Fig. 21 is a graph showing the frequency  
10 characteristics of insertion loss in a transmitting filter and a receiving filter in a comparative example.

Fig. 22 is a cross-sectional view of a piezoelectric thin film resonator used in a fourth preferred embodiment of  
the present invention.

15 Fig. 23 is a graph showing an investigation result of the electromechanical coupling coefficient with the piezoelectric film thickness ratio in the fourth preferred  
embodiment of the present invention.

Fig. 24 is a circuit block diagram of a communication  
20 device including a duplexer according to various preferred  
embodiments of the present invention.

Fig. 25 is a schematic cross-sectional view showing the structure of a resonator of a receiving filter according to  
ana preferred embodiment of the present invention.

~~Best Mode for Carrying Out the Invention~~

~~—f~~

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

First Preferred Embodiment

5        ~~An~~ A preferred embodiment of the present invention will now be described with reference to Figs. 1 to 43.

      In the present preferred embodiment, a duplexer in which the transmission band is about 1,850 ~~to~~ MHz to about 1,910 MHz and the reception band is about 1,930 MHz to about  
10    1,990 MHz will now be described.

      As shown in Fig. 1, the duplexer (branching filter) according to the present preferred embodiment preferably includes a transmitting terminal 1, a receiving terminal 2, and an antenna terminal 3.

15        The duplexer preferably includes a transmitting filter 5, a receiving filter 6, and a matching circuit 7. The transmitting filter 5 is disposed between the antenna terminal 3 and the transmitting terminal 1. The receiving filter 6 is disposed between the antenna terminal 3 and the  
20    receiving terminal 2. The matching circuit 7 is disposed between the antenna terminal 3 and the receiving filter 6.

      In other words, in the duplexer, the transmitting filter 5 and the receiving filter 6 are connected to the antenna terminal 3 in parallel.

25        A capacitance 8 is disposed between the antenna

terminal 3 and the transmitting filter 5.

The pass band in the transmitting filter 5 and that in the receiving filter 6 are set so as to be different from each other.

5        The transmitting filter 5 includes series resonators 11a and 11b and parallel resonators 12a and 12b arranged in a ladder type configuration.

The parallel resonators 12a and 12b are grounded through inductances 13a and 13b.

10       The inductances 13a and 13b can extend the pass band of the transmitting filter 5.

The receiving filter 6 includes series resonators 21a, 21b, and 21c and parallel resonators 22a, 22b, 22c, and 22d arranged in a ladder type configuration.

15       The parallel resonators 22a, 22b, 22c, and 22d are grounded.

The matching circuit 7 includes an inductance 71 connected in series and capacitances 72 and 73 connected in parallel.

20       In the present preferred embodiment, the resonators in the transmitting filter 5 and the receiving filter 6 are piezoelectric thin film resonators. Each of the piezoelectric thin film resonators includes a thin film (piezoelectric thin film) composed of a piezoelectric  
25 material and electrodes that sandwich the piezoelectric thin

film and ~~face~~are opposed to each other.

The characteristics desired for the transmitting filter 5 and the receiving filter 6 wherein the transmitting filter has relatively low frequency characteristics and the  
5 receiving filter has relatively high frequency characteristics will now be described.

A large electric power is applied to the transmitting filter 5.

Therefore, the resonators used in the transmitting  
10 filter 5 preferably have a high Q factor.

This Q factor represents the mechanical vibration loss in a resonator.

Since a low Q factor increases the mechanical vibration loss in the resonator, the loss causes heat and the  
15 resonator generates heat. As a result, the lifetime of the resonator is shortened.

Furthermore, the lifetime of the transmitting filter 5 is also shortened.

The Q factor depends on the structure of the resonator.  
20 Furthermore, the smaller the elastic loss of the material used in the resonator, the higher the Q factor is.

Since the elastic loss of materials also depends on the frequency etc., it is difficult to mention the specific values. However, propagation loss, which is often used in,  
25 for example, a surface acoustic wave device, is an indicator.

That is, the smaller the propagation loss of the material used in the resonator, the higher the Q factor of the resonator is.

A material having a high thermal conductivity is  
5 preferably used as the resonators in the transmitting filter  
5.

The reason for this is as follows: A low thermal conductivity decreases the heat dissipation effect. As a result, the resonator is heated and the lifetime of the  
10 resonator is shortened.

The electromechanical coupling coefficient  $k^2$  (effective coupling coefficient  $k_{eff}^2$ ) of the resonators in the transmitting filter 5 is preferably about 3% to about 4%.

The reason for this is as follows: Even when the  
15 electromechanical coupling coefficient  $k_{eff}^2$  is small, the pass band can be extended to the low frequency side to some degree with an external circuit (for example, an extended inductance).

When the electromechanical coupling coefficient  $k_{eff}^2$  is  
20 about 5% or more, roll-off characteristics at the high frequency side (i.e., the steepness of the attenuation in the range from the pass band of about 1,910 MHz in the transmitting to the pass band of about 1,930 MHz in the receiving) is deteriorated.

25 The use of a material having a large electromechanical

coupling coefficient  $k^2$  as the piezoelectric thin film increases the  $k_{\text{eff}}^2$  of the resonator.

The electromechanical coupling coefficient  $k_{\text{eff}}^2$  also depends on the structure of the resonator.

5        In the receiving filter 6, when the pass band is extended to the low frequency side with an external circuit, the receiving filter 6 interferes with the transmitting filter 5.

10       In addition, an external circuit cannot extend the pass band to the high frequency side.

For these reasons, in the receiving filter 6, a predetermined filter band must be provided using resonators having a large electromechanical coupling coefficient  $k_{\text{eff}}^2$  and without an auxiliary external circuit.

15       The structure of the piezoelectric thin film resonator of the transmitting filter 5 and the piezoelectric thin film resonator of the receiving filter 6 having the above-described characteristics will now be described in detail with reference to Figs. 2 and 3.

20       As shown in Fig. 2, a resonator of the transmitting filter 5 includes a supporting substrate ~~(substrate)~~ 32 preferably composed of silicon (Si) and an insulating film 31 disposed on the supporting substrate 32.

25       Furthermore, the supporting substrate 32 includes an opening ~~(or hollow part)~~ portion that penetrates the

supporting substrate 32 in the direction of the thickness and extends to the other side of the insulating film 31.

A lower electrode ~~(electrode)~~ 33, a piezoelectric thin film 34, and an upper electrode ~~(electrode)~~ 35 are disposed  
5 on the insulating film 31 in that order.

The insulating film 31 forms a diaphragm.

This diaphragm faces the opening ~~(or hollow part)~~portion.

As shown in Fig. 3, a resonator of the receiving filter  
10 6 includes a supporting substrate ~~(substrate)~~ 42 composed of silicon (Si) and an insulating film 41 disposed on the supporting substrate 42.

Furthermore, the supporting substrate 42 includes an opening ~~(or hollow part)~~portion that penetrates the  
15 supporting substrate 42 in the direction of the thickness and extends to the insulating film 41.

A lower electrode 43, a piezoelectric thin film 44, and an upper electrode 45 are disposed on the insulating film 41 in that order.

20 The insulating film 41 forms a diaphragm.

This diaphragm faces the opening ~~(or hollow part)~~portion.

Second harmonic waves are used in the resonators shown in Figs. 2 and 3.

25 In the present preferred embodiment, the ~~kind~~type of

the piezoelectric thin film is different between the resonators of the transmitting filter 5 and the resonators of the receiving filter 6.

In the resonators of the transmitting filter 5, the piezoelectric thin film 34 is preferably composed of AlN, the insulating film 31 is preferably composed of SiO<sub>2</sub>, and the lower electrode 33 and the upper electrode 35 are preferably composed of Au/Ti.

In the resonators of the receiving filter 6, the piezoelectric thin film 4544 is preferably composed of ZnO, the insulating film 41 is preferably composed of SiO<sub>2</sub>, and the lower electrode 43 and the upper electrode 45 are preferably composed of Au/Ti.

The resonators of the transmitting filter 5 will now be described in more detail.

Aluminum nitride (AlN) has a thermal conductivity that is higher than that of ZnO and has an elastic loss that is smaller than that of ZnO.

Aluminum nitride (AlN) has a small electromechanical coupling coefficient ( $k_t=0.23$ , thermal conductivity  $W/(m \cdot ^\circ C)=150$ ).

Accordingly, the resonators of the transmitting filter 5 have a Q factor and a heat dissipation effect higher than those of the resonators of the receiving filter 6.

Furthermore, in the resonators of the transmitting

filter 5, the insulating film 31 composed of  $\text{SiO}_2$  is preferably used. Therefore, the sign of the temperature coefficient of the insulating film 31 composed of  $\text{SiO}_2$  and that of the piezoelectric thin film 34 composed of AlN are  
5 opposite with respect to each other.

Therefore, the temperature change is cancelled out in the piezoelectric thin film 34 and the insulating film 31. As a result, the temperature characteristics in the resonators of the transmitting filter 5 can be improved.

10 The acoustic velocity in AlN is larger than that in ZnO. In order to obtain ~~the equivalent a frequency as that is~~ equivalent to that of the resonator using ZnO, the film thickness of the diaphragm must be increased or an electrode material having a large density must be used.

15 When the film thickness of AlN is increased, the area (vibration ~~part~~portion) where the upper electrode 35 is overlapped with the lower electrode 33 must be increased in order that the capacitance ( $C_0$ ) of the resonator is controlled to be a predetermined value. As a result, the  
20 element size is increased.

However, a metal having a density of at least about 8  $\text{g/cm}^3$  (for example, Au: 19.3, Pt: 21.45, Ni: 8.9, and Mo: 10.4) can be used as at least one of the upper electrode 35 and the lower electrode 33. In this case, the predetermined  
25 frequency can be obtained without increasing the area of the

upper electrode 35 or the lower electrode 33.

The resonators of the receiving filter 6 will now be described in more detail.

Zinc oxide (ZnO) has an electromechanical coupling  
5 coefficient that is larger than that of AlN ( $k_t=0.30$ ).

Accordingly, the resonators of the receiving filter 6 have a large electromechanical coupling coefficient  $k_{eff}^2$ .

Zinc oxide (ZnO) has a thermal conductivity lower than that of AlN (thermal conductivity  $W/(m \cdot ^\circ C)=4$ ).

10 Furthermore, in the resonators of the receiving filter 6, the insulating film 41 that is preferably composed of  $SiO_2$  is used.

Therefore, the ~~sign~~sign of the temperature coefficient of the insulating film 41 composed of  $SiO_2$  and that of the  
15 piezoelectric thin film 44 composed of ZnO are opposite with respect to each other.

Therefore, the temperature change is cancelled out in the piezoelectric thin film 44 and the insulating film 41. As a result, the temperature characteristics in the  
20 resonators of the receiving filter 6 can be improved.

In the resonators of the transmitting filter 5, AlN having a small electromechanical coupling coefficient  $k_{eff}^2$  is used as the piezoelectric thin film 34. Therefore, the electromechanical coupling coefficient  $k_{eff}^2$  of the  
25 resonators of the transmitting filter is smaller than that

of the resonators of the receiving filter.

As shown in Fig. 1, the inductances 13a and 13b are connected to the parallel resonators 12a and 12b of the transmitting filter 5. Therefore, in this case, the pass  
5 band can be extended to the low frequency side, thereby obtaining the desired bandwidth.

—{

Second Preferred Embodiment{

~~An~~Another preferred embodiment of the present invention  
10 will now be described with reference to Figs. 4 to 8.

For the convenience of description, components having the same function as those of the components shown in the first preferred embodiment have the same reference numerals and the description is omitted.

15 In the present preferred embodiment, as shown in Fig. 4, an insulating film 41 in the resonators of the receiving filter 6 is preferably composed of two layers: An insulating film 41a is disposed on a substrate 42 and an insulating film 41b is disposed on the insulating film 41a.

20 In the present preferred embodiment, the insulating film 41a is preferably composed of  $Al_2O_3$  and the insulating film 41b is preferably composed of  $SiO_2$ .

In this structure, a compressive stress is applied on the piezoelectric thin film 44 composed of ZnO and the  
25 insulating film 41b composed of  $SiO_2$ , whereas a tensile

stress is applied on the insulating film 41a composed of  $\text{Al}_2\text{O}_3$ .

This structure ~~can stabilize~~stabilizes the strength of the diaphragm.

5 In the present preferred embodiment, the insulating film 41a may be composed of AlN.

In this case, the ~~sign~~sign of the temperature coefficient of the insulating film 41a composed of AlN and that of the insulating film 41b composed of  $\text{SiO}_2$  are  
10 opposite with respect to each other.

Therefore, the temperature change is cancelled out in the insulating film 41a and the insulating film 41b. As a result, the temperature characteristics in the resonators of the receiving filter 6 ~~can be~~are greatly improved.

15 Furthermore, since AlN is superior in the thermal conductivity compared with  $\text{Al}_2\text{O}_3$ , the heat dissipation effect can be improved.

The above-described structure can increase the electromechanical coupling coefficient  $k_{\text{eff}}^2$ .

20 This is because the acoustic impedance of  $\text{SiO}_2$  ~~forming~~defining the insulating film 41b is about  $1.3 \times 10^7$  ( $\text{N} \cdot \text{s}/\text{m}^3$ ), which is smaller than that of ZnO (about  $3.5 \times 10^7$  ( $\text{N} \cdot \text{s}/\text{m}^3$ )) ~~forming~~defining the piezoelectric thin film 44, that of  $\text{Al}_2\text{O}_3$  (about  $3.9 \times 10^7$  ( $\text{N} \cdot \text{s}/\text{m}^3$ )) and that of AlN (about  
25  $3.5 \times 10^7$  ( $\text{N} \cdot \text{s}/\text{m}^3$ )) ~~forming~~defining the insulating film 41a.

In other words, acoustic waves are significantly reflected at the interface between the piezoelectric thin film 44 and the insulating film 41b, and the energy of the acoustic waves is concentrated on the piezoelectric thin film 44. Accordingly, the electromechanical coupling coefficient  $k_{\text{eff}}^2$  can be increased.

As shown in the displacement diagram of vibration in Fig. 5, the displacement of vibration in ZnO of the piezoelectric thin film 44 is larger than that in SiO<sub>2</sub> of the insulating film 41b.

The thickness of the piezoelectric thin film 44, the insulating film 41a composed of Al<sub>2</sub>O<sub>3</sub>, and the insulating film 41b composed of SiO<sub>2</sub> will now be described. As shown in Fig. 6, in terms of large electromechanical coupling coefficient  $k_{\text{eff}}^2$ , the film thickness ratio represented by the thickness of the piezoelectric thin film 44 : (the thickness of the insulating film 41a composed of Al<sub>2</sub>O<sub>3</sub> + the thickness of the insulating film 41b composed of SiO<sub>2</sub>) is preferably about 0.7 to about 1.3.

Furthermore, as shown in Fig. 7, in terms of high Q factor, the film thickness ratio is preferably about 0.6 to about 0.8.

As shown in Fig. 8, in terms of small absolute value of the temperature coefficient of frequency (TCF), the film thickness ratio represented by the insulating film 41a

(Al<sub>2</sub>O<sub>3</sub>) : the insulating film 41b (SiO<sub>2</sub>) is preferably about 1 or more.

However, when the ratio of the insulating film 41a to the insulating film 41b is excessively small, the problem of stress balance occurs. Therefore, the film thickness ratio represented by the insulating film 41a (Al<sub>2</sub>O<sub>3</sub>)—: the insulating film 41b (SiO<sub>2</sub>) is more preferably about 1 to about 3.

In Figs. 6 to 8, the piezoelectric thin film 44 is preferably composed of ZnO, the insulating film 41a is preferably composed of Al<sub>2</sub>O<sub>3</sub>, and the insulating film 41b is preferably composed of SiO<sub>2</sub>.

The upper electrode 45 and the lower electrode 43 that sandwich the piezoelectric thin film 44 are preferably composed of Al and have a film thickness of about 180 nm.

The figures show the calculation results in which the film thickness ratio of the insulating film 41b (SiO<sub>2</sub>) to the insulating film 41a (Al<sub>2</sub>O<sub>3</sub>) is varied from about 3:1 to about 1:3 under the above-described conditions.

The absolute amount of each film thickness is determined such that the frequency band of the resonators is controlled to be about 1,900 MHz.

——{

——Third Preferred Embodiment}

25     ~~Another~~ further preferred embodiment of the present

invention will now be described with reference to Figs. 9 to 17.

For the convenience of description, components having the same function as those of the components shown in the first preferred embodiment and the second preferred 5 embodiment have the same reference numerals and the description is omitted.

In the present preferred embodiment, as shown in Fig. 9, an insulating film 31 in the resonators of the transmitting 10 filter 5 is preferably composed of two layers: An insulating film 31a is disposed on a substrate 32 and an insulating film 31b is disposed on the insulating film 31a.

In the present preferred embodiment, the insulating film 31a is preferably composed of  $\text{SiO}_2$  and the insulating 15 film 31b is preferably composed of AlN.

In this case, since AlN is superior in the thermal conductivity, the heat dissipation effect of the element can be improved.

This structure can achieve high withstand power, extend 20 the lifetime, and improve the reliability of the element.

In the present preferred embodiment, the insulating film 31a may be composed of  $\text{SiO}_2$  and the insulating film 31b may be composed of  $\text{Al}_2\text{O}_3$ .

In this structure, a compressive stress is applied on 25 the insulating film 31a composed of  $\text{SiO}_2$ , whereas a tensile

stress is applied on the insulating film 31b composed of  $\text{Al}_2\text{O}_3$ .

This structure can stabilize the strength of the diaphragm.

5       The above-described structure can decrease the absolute value of the temperature coefficient of frequency (TCF).

The reason for this is as follows: The temperature coefficient of  $\text{ZnO}$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{AlN}$  that are used as the piezoelectric thin film 34 or the insulating film 31b is  
10       negative (i.e., the rise in temperature decreases the frequency). On the other hand, the temperature coefficient of  $\text{SiO}_2$  used as the insulating film 31a is positive.

As shown in the displacement diagram of vibration in Fig. 10 (wherein  $\text{ZnO}$  is used as the piezoelectric thin film  
15       34), the displacement of vibration in  $\text{ZnO}$  of the piezoelectric thin film 34 is strongly affected by the temperature coefficient of  $\text{SiO}_2$  ~~forming~~defining the insulating film 31a. As a result, the TCF of the whole resonator is shifted in the positive direction (i.e., comes  
20       close to zero).

When the above-described piezoelectric thin film 34, the insulating film 31a composed of  $\text{SiO}_2$ , and the insulating film 31b composed of  $\text{Al}_2\text{O}_3$  are used, the thickness of the insulating film 31a and the insulating film 31b is  
25       preferably as follows. As shown in Figs. 11 and 12, in

terms of large electromechanical coupling coefficient  $k_{\text{eff}}^2$  and high Q factor, since the dependency to the thickness of the piezoelectric thin film 34 is small, the film thickness ratio is not particularly limited. However, the film thickness ratio represented by the thickness of the piezoelectric thin film 34 : (the thickness of the insulating film 31a composed of  $\text{SiO}_2$  + the thickness of the insulating film 31b composed of  $\text{Al}_2\text{O}_3$ ) is preferably about 0.7 to about 1.2.

As shown in Fig. 13, in terms of small absolute value of the temperature coefficient of frequency (TCF), the film thickness ratio represented by the insulating film 31a ( $\text{SiO}_2$ ) : the insulating film 31b ( $\text{Al}_2\text{O}_3$ ) is preferably about 1 or more.

However, when the ratio of the insulating film 31a ( $\text{SiO}_2$ ) to the insulating film 31b ( $\text{Al}_2\text{O}_3$ ) is excessively small, the problem of stress balance occurs. Therefore, the film thickness ratio represented by the insulating film 31a ( $\text{SiO}_2$ ) : the insulating film 31b ( $\text{Al}_2\text{O}_3$ ) is more preferably about 1 to about 3.

In Figs. 11 to 13, the piezoelectric thin film 34 is preferably composed of  $\text{ZnO}$ , the insulating film 31a is preferably composed of  $\text{SiO}_2$ , and the insulating film 31b is preferably composed of  $\text{Al}_2\text{O}_3$ .

The upper electrode 35 and the lower electrode 33 that

sandwich the piezoelectric thin film 34 are preferably composed of Al and preferably have a film thickness of about 180 nm.

The figures show the calculation results in which the  
5 film thickness ratio of the insulating film 31b ( $\text{Al}_2\text{O}_3$ ) to the insulating film 31a ( $\text{SiO}_2$ ) is varied from about 3:1 to about 1:3 under the above conditions.

The absolute amount of each film thickness is determined such that the frequency band of the resonators is  
10 controlled to be about 1,900 MHz.

As shown in Fig. 14, the receiving filter may include two series resonators and three parallel resonators.

As shown in Fig. 15, in the transmitting filter, a resonator may be added in series adjacent to the  
15 transmitting terminal. The matching circuit may include two inductances connected in series and a capacitance connected in parallel. Furthermore, the capacitance 8 may be omitted.

As shown in Fig. 16, each of the series resonators in the transmitting filter in Fig. 14 may be replaced with two  
20 series resonators.

A modification of the resonator in the transmitting filter 5 and the receiving filter 6 will now be described with reference to Fig. 17.

As shown in Fig. 17, the resonator includes an  
25 insulating film 51 on a recess 56 disposed on a substrate 52.

The insulating film 51 is suspended over the recess 56 at the periphery.

A lower electrode 53, a piezoelectric thin film 54, and an upper electrode 55 are disposed on the insulating film 51.

5       The above-described structures of the piezoelectric thin film and the insulating film in the transmitting filter 5 and the receiving filter 6 can be applied to this structure. Thus, the same advantages can be achieved in this structure.

10       In addition, when the resonators of the transmitting filter 5 and the resonators of receiving filter 6 are composed of the same materials and are different only in the deposited order, the same deposition equipment can be used to reduce the cost.

15       The transmitting filter 5 ~~using~~including resonators including a piezoelectric thin film 34 preferably composed of ZnO, an insulating film 31a preferably composed of SiO<sub>2</sub>, and an insulating film 31b preferably composed of AlN can achieve a Q factor of about 700 and an electromechanical  
20 coupling coefficient  $k^2_{\text{eff}}$  of about 2.9%.

      The receiving filter 6 ~~using~~including resonators ~~including~~having a piezoelectric thin film 44 composed of ZnO, an insulating film 41a composed of Al<sub>2</sub>O<sub>3</sub>, and an insulating film 41b composed of SiO<sub>2</sub> can achieve a Q factor of 400 and  
25 an electromechanical coupling coefficient  $k^2_{\text{eff}}$  of about 5.3%.

Figs. 18 and 19 show the frequency characteristics of insertion loss in the transmitting filter 5 and the receiving filter 6.

In the transmitting filter 5, the inductances are  
5 connected to the parallel resonators. Therefore, as shown in Figs. 18 and 19, the bandwidth can be extended to the low frequency side despite the small electromechanical coupling coefficient  $k_{\text{eff}}^2$ .

In contrast, in the receiving filter 6, the bandwidth  
10 can be increased because of the large electromechanical coupling coefficient  $k_{\text{eff}}^2$ .

As shown in Fig. 19, regarding the bandwidth wherein the level is attenuated by about 3.5 dB, the transmitting filter 5 can provide the bandwidth of about 80 MHz, and the  
15 receiving filter 6 can provide the bandwidth of about 68 MHz.

As a comparative example, a receiving filter 6 ~~using~~  
including resonators including having a piezoelectric thin  
film 44 preferably composed of ZnO, an insulating film 41a  
preferably composed of SiO<sub>2</sub>, and an insulating film 41b  
20 preferably composed of AlN is used. The resonators have a Q factor of about 700 and an electromechanical coupling coefficient  $k_{\text{eff}}^2$  of about 2.9%. As shown in Figs. 20 and 21, in this receiving filter 6, the bandwidth wherein the level is attenuated by about 3.5 dB is no more than about 36 MHz.

25 ———{

Fourth Preferred Embodiment

In the present preferred embodiment, the resonance characteristics in a piezoelectric thin film resonator 100 shown in Fig. 22 were investigated.

5       The piezoelectric thin film resonator 100 includes a supporting substrate ~~(substrate)~~ 102 preferably composed of silicon (Si).

      A lower electrode ~~(electrode)~~ 103, a piezoelectric thin film 104 composed of ZnO, and an upper electrode ~~(electrode)~~ 105 are disposed on the supporting substrate 102 in that order.

      Furthermore, the supporting substrate 102 includes an opening ~~(or hollow part)~~ portion that penetrates the supporting substrate 102 in the direction of the thickness and extends to the other side of the lower electrode 103.

      A diaphragm facing the opening ~~(or hollow part)~~ portion is formed.

      In this experiment, the upper electrode 105 and the lower electrode 103 in the piezoelectric thin film resonator 100 were composed of the same material and had the same film thickness.

      The material of the electrodes used in this example was aluminum Al, molybdenum Mo, copper Cu, tungsten W, and platinum Pt.

25       Fig. 23 shows the investigation result of the

relationship between a piezoelectric film thickness ratio and the electromechanical coupling coefficient ( $k_{\text{eff}}^2$ ) concerning the various materials of the electrodes. The piezoelectric film thickness ratio is the ratio of the film thickness of the piezoelectric thin film to the total film thickness (the thickness of the upper electrode 105 + the thickness of the piezoelectric thin film 104 + the thickness of the lower electrode 103) of the resonator.

As shown in Fig. 23, when the piezoelectric film thickness ratio was optimally selected, among the above-described five kinds of materials of the electrodes, the highest electromechanical coupling coefficient ( $k_{\text{eff}}^2$ ) was achieved with W, and subsequently, Pt, Mo, Cu, and Al, in that order.

Table 1 shows the approximate acoustic impedance and the resistivity in the materials of the electrodes.

{Table 1}

Material of electrodes	Acoustic impedance (Ns/m <sup>3</sup> )	Resistivity ( $\mu\Omega\text{cm}$ )
W	$1.0 \times 10^8$	5.5
Pt	$7.5 \times 10^7$	10.6
Mo	$6.9 \times 10^7$	5.7
Cu	$3.9 \times 10^7$	1.7

Al	$1.7 \times 10^7$	2.7
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Referring to Fig. 23 and Table 1, the higher the acoustic impedance of the material, the higher the electromechanical coupling coefficient ( $k_{\text{eff}}^2$ ) can be.

5        As shown in the first preferred embodiment to the third preferred embodiment, resonators having a large electromechanical coupling coefficient ( $k_{\text{eff}}^2$ ) must be used in a filter (for example, receiving filter) disposed at the high frequency side of the duplexer.

10       In a filter (for example, transmitting filter) disposed at the low frequency side, the band can be extended by providing an external inductance. Therefore, even when resonators having a small electromechanical coupling coefficient ( $k_{\text{eff}}^2$ ) are used, the steepness of the filter can  
15 be provided.

Accordingly, in the receiving filter, a material that has high acoustic impedance to increase the electromechanical coupling coefficient ( $k_{\text{eff}}^2$ ) is preferably used as the electrodes.

20       On the other hand, in the transmitting filter, copper or aluminum that has low acoustic impedance but has a low resistivity is preferably used ~~as to~~ to form the electrodes. Thus, a duplexer having excellent characteristics can be

produced.

—+—

Fifth Preferred Embodiment+

~~An~~Another preferred embodiment of the present invention  
5 will now be described with reference to Fig. 25.

For the convenience of description, components having  
the same function as those of the components shown in the  
first preferred embodiment to the fourth preferred  
embodiment have the same reference numerals and the  
10 description is omitted.

In the present preferred embodiment, as shown in Fig.  
25, resonators of a receiving filter 6 can use fundamental  
waves.

The resonators using fundamental waves can have an  
15 electromechanical coupling coefficient  $k_{\text{eff}}^2$  that is larger  
than that of the resonators using second harmonic waves,  
which are shown in Figs. 2 to 4 and Fig. 9.

Consequently, a pass band required in the receiving  
filter can be provided.

20 For example, a duplexer may include resonators of the  
receiving filter 6 having a piezoelectric thin film  
preferably composed of AlN and using fundamental waves, and  
resonators of the transmitting filter 5 having a  
piezoelectric thin film preferably composed of ZnO and using  
25 second harmonic waves. Thus, a duplexer having excellent

characteristics can be achieved.

A communication device using the duplexer described in the above-described preferred embodiment will now be described with reference to Fig. 24.

5        At the receiving side (Rx side) wherein receiving is performed, the communication device 600 includes an antenna 601, an antenna common / RF Top filter 602, an amplifier 603, an Rx interstage filter 604, a mixer 605, a 1st IF filter 606, a mixer 607, a 2nd IF filter 608, a 1st+2nd local  
10 synthesizer 611, a temperature compensated crystal oscillator (TCXO) 612, a divider 613, and a local filter 614.

As shown by the double lines in Fig. 24, the transmitting from the Rx interstage filter 604 to the mixer 605 is preferably performed with balanced signals so as to  
15 secure the balance.

At the transceiving side (Tx side) wherein transmitting is performed, the communication device 600 shares the antenna 601 and the antenna common / RF Top filter 602, and includes a Tx IF filter 621, a mixer 622, a Tx interstage  
20 filter 623, an amplifier 624, a coupler 625, an isolator 626, and an automatic power control (APC) 627.

The duplexer of the above-described ~~in the above~~ preferred embodiment can be suitably used as the Rx interstage filter 604 and the RF Top filter 602.

25        The present invention is not limited to the above-

described preferred embodiments and various modifications are possible within the scope shown in the claims. The technical field of the present invention also includes embodiments obtained by appropriately combining technical  
5 methods disclosed in the different embodiments.

~~Industrial Applicability~~

The branching filter including filters having piezoelectric thin film resonators of the present invention  
10 can be applied to various communication devices such as a cellular phone.

CLAIMS

~~1. A branching filter comprising a transmitting filter~~  
15 ~~and~~ While the present invention has been described with respect to preferred embodiments, it will be apparent to those skilled in the art that the disclosed invention may be modified in numerous ways and may assume many embodiments other than those specifically set out and described above.  
20 Accordingly, it is intended by the appended claims to cover all modifications of the invention which fall within the true spirit and scope of the invention.

What is Claimed is:

1. A branching filter comprising:  
a transmitting filter; and  
a receiving filter; wherein  
piezoelectric thin film resonators including at least  
one piezoelectric thin film sandwiched between at least one  
pair of ~~facing~~opposed electrodes are ~~disposed~~arranged in a  
ladder ~~type~~configuration on an opening or a recess of a  
substrate, the transmitting filter and the receiving filter  
being connected to an antenna terminal in parallel; and  
wherein  
the piezoelectric thin film resonators ~~forming~~defining  
the transmitting filter and the piezoelectric thin film  
resonators ~~forming~~defining the receiving filter ~~comprise~~have  
a different structure from each other.

2. The branching filter according to claim 1, wherein  
the piezoelectric thin film resonators ~~forming~~defining the  
transmitting filter and the piezoelectric thin film  
resonators ~~forming~~defining the receiving filter ~~comprise~~  
~~have~~ different piezoelectric films.

3. The branching filter according to claim 2, wherein  
the piezoelectric film of the piezoelectric thin film

resonators ~~forming~~defining the transmitting filter ~~comprises~~  
includes AlN and the piezoelectric film of the piezoelectric  
thin film resonators ~~forming~~defining the receiving filter  
~~comprises~~includes ZnO.

\_\_\_\_ 4. The branching filter according to claim 1, wherein  
the material of the electrodes is different between the  
piezoelectric thin film resonators ~~forming~~defining the  
transmitting filter and the piezoelectric thin film  
resonators ~~forming~~defining the receiving filter.

\_\_\_\_ 5. The branching filter according to claim 4, wherein  
the acoustic impedance of the material of the electrodes is  
different between the piezoelectric thin film resonators  
~~forming~~defining the transmitting filter and the  
piezoelectric thin film resonators ~~forming~~defining the  
receiving filter.

\_\_\_\_ 6. The branching filter according to claim 4, wherein  
the frequency of the pass band of the receiving filter is  
higher than the frequency of the pass band of the  
transmitting filter, and the acoustic impedance of the  
material of the electrodes ~~forming~~defining the receiving  
filter is higher than the acoustic impedance of the material  
of the electrodes ~~forming~~defining the transmitting filter.

\_\_\_\_ 7. The branching filter according to claim 1, wherein the piezoelectric thin film resonators ~~forming~~defining the transmitting filter use second harmonic waves and the piezoelectric thin film resonators ~~forming~~defining the receiving filter use fundamental waves.

\_\_\_\_ 8. The branching filter according to claim 1, wherein the piezoelectric thin film resonators ~~forming~~defining the transmitting filter and the piezoelectric thin film resonators ~~forming~~defining the receiving filter further comprise a different insulating film on the opening or the recess of the substrate.

\_\_\_\_ 9. The branching filter according to claim 8, wherein the insulating film of the piezoelectric thin film resonators ~~forming~~defining the receiving filter comprises  $\text{SiO}_2$ .

\_\_\_\_ 10. The branching filter according to claim 8, wherein the insulating film of the piezoelectric thin film resonators ~~forming~~defining the receiving filter comprises two layers ~~comprising~~including an  $\text{SiO}_2$  layer adjacent to the piezoelectric thin film and an  $\text{Al}_2\text{O}_3$  layer adjacent to the  $\text{SiO}_2$  layer.

\_\_\_\_ 11. The branching filter according to claim 8, wherein the insulating film of the piezoelectric thin film resonators ~~forming~~defining the receiving filter comprises two layers ~~comprising~~including an SiO<sub>2</sub> layer adjacent to the piezoelectric thin film and an AlN layer adjacent to the SiO<sub>2</sub> layer.

\_\_\_\_ 12. The branching filter according to claim 8, wherein the insulating film of the piezoelectric thin film resonators ~~forming~~defining the transmitting filter comprises two layers ~~comprising~~including an AlN layer adjacent to the piezoelectric thin film and an SiO<sub>2</sub> layer adjacent to the AlN layer.

\_\_\_\_ 13. The branching filter according to claim 8, wherein the insulating film of the piezoelectric thin film resonators ~~forming~~defining the transmitting filter comprises two layers ~~comprising~~including an Al<sub>2</sub>O<sub>3</sub> layer adjacent to the piezoelectric thin film and an SiO<sub>2</sub> layer adjacent to the Al<sub>2</sub>O<sub>3</sub> layer.

\_\_\_\_ 14. A communication device comprising the branching filter according to ~~any one of claims~~ claim 1 to 13.

# ABSTRACT OF THE DISCLOSURE

A branching filter and a communication device ~~having~~have excellent characteristics ~~are provided in which~~  
~~the~~and an optimized configuration of the ~~a~~ transmitting  
filter and ~~the~~ a receiving filter ~~is optimized~~. The  
branching filter includes a transmitting filter ~~5~~ and a  
receiving filter ~~5~~ wherein piezoelectric thin film  
resonators ~~11a, 11b, 12a, 12b, 21a to 21e, and 22a to 22d~~  
including a piezoelectric thin film sandwiched between  
~~face~~opposed electrodes are ~~disposed~~arranged in a ladder  
~~type~~type configuration on an opening or a recess of a  
substrate. The transmitting filter ~~5~~ and the receiving  
filter ~~6~~ are connected in parallel to an antenna terminal ~~3~~  
~~in parallel~~. The piezoelectric thin film resonators ~~11a,~~  
~~11b, 12a, and 12b~~ formingdefining the transmitting filter ~~5~~  
and the piezoelectric thin film resonators ~~21a to 21e and~~  
~~22a to 22d~~ formingdefining the receiving filter ~~6~~ are  
different from each other.